

**AN INTERNATIONAL DESIGN STANDARD FOR  
OFFSHORE WIND TURBINES: IEC 61400-3**

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**Abstract**

It is clear that the safety and integrity of offshore wind turbines will be considerably improved through the availability and use of relevant and reliable design standards. Although national certification rules and standards for offshore wind turbines have been published in Germany and Denmark, there is an evident need for an international standard for offshore wind turbines. This need has been recognised within the International Electrotechnical Commission (IEC) and a Working Group (TC88 WG3) has been established to develop such a standard. The declared objective of this Working Group is "to develop an international standard for the engineering and technical requirements which should be considered during design in order to ensure the safety of systems and components of offshore wind turbines, inclusive of their support structures". The standard will be documented in IEC 61400-3 and will cover only those issues relevant to offshore wind turbines, fully consistent with but not duplicating the equivalent onshore wind turbine design standard IEC 61400-1.

In recent years enormous progress has been made with the development of sophisticated standards such as IEC 61400-1 to aid the design of onshore wind turbines. In parallel there have been major advances in the international standardisation of methods used by the offshore engineering community for the design analysis of conventional offshore structures. The work undertaken by WG3 has brought together expert knowledge from the wind power and offshore engineering industries in order to formulate a state of the art guideline specification of the design requirements for offshore wind turbines.

For the purposes of the international standard, it is proposed that a wind turbine be considered "offshore" if the support structure is subject to hydrodynamic loading. The main issues which have been considered are: external conditions, design load cases, calculation methods, structural design, and assembly, site assessment, installation erection, commissioning and maintenance.

This paper will report on the completion of the draft standard by WG3. Key issues and problem areas tackled by WG3 will be discussed, the contents of the draft standard will be described, and the anticipated timetable to publication of the international standard will be outlined.

## **1 – Introduction**

Although national certification rules and design recommendations for offshore wind turbines have been published [1, 2, 3] there is a clear need for an international standard for offshore wind turbines. This need has been recognised within the International Electrotechnical Commission (IEC) and a Working Group (TC88 WG3) has been established to develop such a standard. The declared objective of this Working Group is “to develop an international standard for the engineering and technical requirements which should be considered during design in order to ensure the safety of systems and components of offshore wind turbines, inclusive of their support structures”. The standard will be documented in IEC 61400-3 and will cover only those issues relevant to offshore wind turbines, fully consistent with and not duplicating the requirements of the equivalent onshore standard IEC 61400-1 [4].

In recent years enormous progress has been made with the development of sophisticated standards such as IEC 61400-1 to aid the design of onshore wind turbines. In parallel there have been major advances in the methods used by the offshore engineering community for the design analysis of conventional offshore structures. Of particular relevance is the current development of the ISO 19901 series of standards dealing with offshore structures for the petroleum and natural gas industries [5]. The work underway within WG3 has brought together expert knowledge from the wind power and offshore engineering industries in order to formulate a state of the art guideline specification of the design requirements for offshore wind turbines.

## **2 – Scope of the standard**

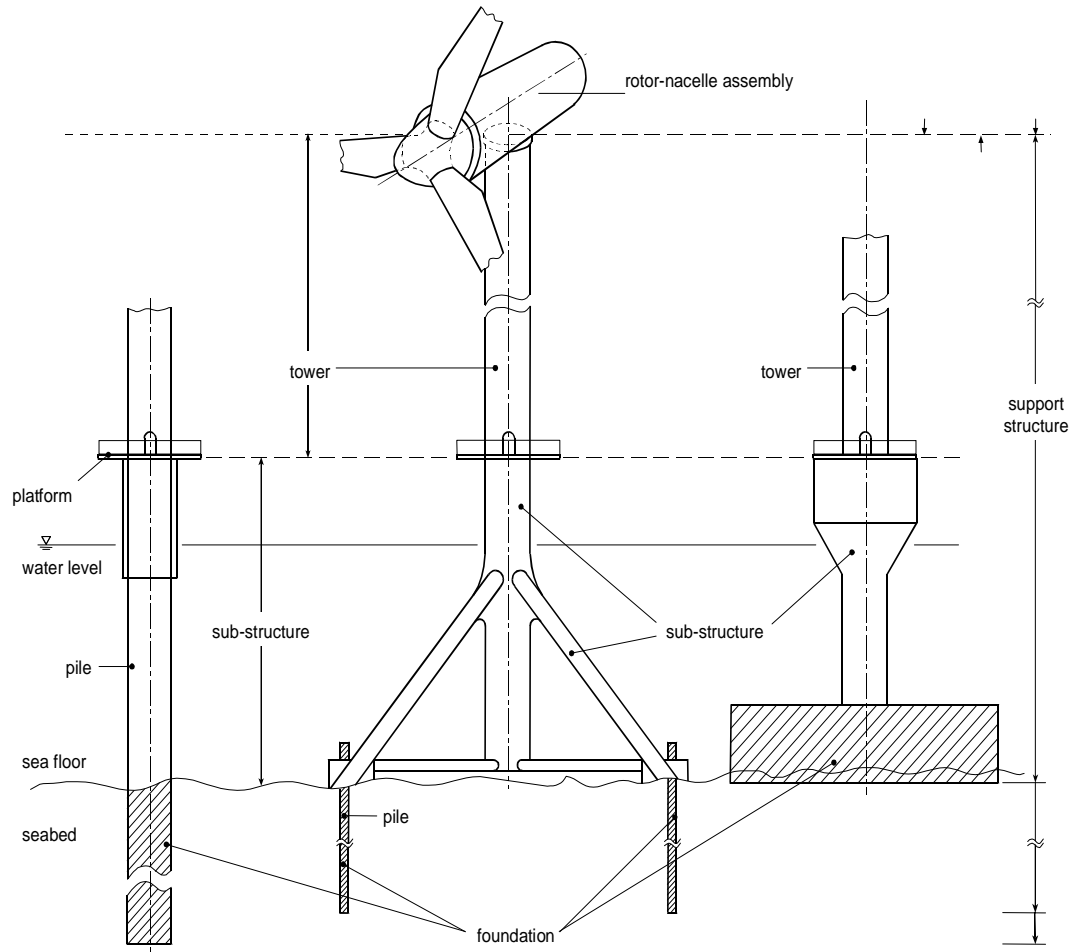
For the purposes of the international standard, it is proposed that a wind turbine be considered “offshore” if the support structure is subject to hydrodynamic loading. Although the standard will therefore be relevant to both “bottom – mounted” and floating offshore wind turbines, the design requirements specified in the standard are not sufficient to ensure the engineering integrity of floating wind turbines.

An important distinction is made in the draft standard between the approach required for the design of a “support structure” of an offshore wind turbine and the treatment of the “rotor – nacelle assembly”. In this context the support structure is defined as the combination of the tower, sub-structure and foundation, whereas the rotor – nacelle assembly is that part of the wind turbine carried by the support structure, refer Figure 1 below.

The standard proposes that the design of the support structure must be based on environmental conditions which are representative of the site at which the offshore wind turbine will be installed. This requirement is made because of the highly site dependent nature of the marine environmental conditions which include waves, currents, water depth, seabed properties, sea ice and marine growth. The marine conditions are, in general, of great importance for the design of the support structure.

Wind conditions are the primary external consideration for the structural integrity of the rotor – nacelle assembly, although the marine conditions may also have an influence in some cases depending on the dynamic properties of the support structure. In most cases the rotor – nacelle assembly of an offshore wind turbine will be designed not for a specific site but rather to be suitable for a wide range of environments. The designer may therefore assume generic external conditions which reflect an environment at least as severe as is anticipated for the use of the wind turbine. The draft standard does, however, require that in all cases the structural integrity of the rotor – nacelle assembly must be demonstrated taking proper account of the environmental conditions (wind, marine etc.) at each specific site at which the offshore wind turbine will be subsequently installed.

It is clear from above that both the design of the support structure of an offshore wind turbine and the demonstration of structural integrity of the rotor – nacelle assembly require an assessment of the external conditions at the intended site. The procedures for such a site assessment will form an integral part of the standard.



**Figure 1 – Main parts of an offshore wind turbine**

## 2.1 – External conditions

In the international onshore design standard, IEC 61400-1, wind turbine classes are defined in terms of wind speed and turbulence parameters, refer Table 1 below. The values of these parameters are intended to represent the characteristic values of many different sites and do not give a precise representation of any specific site. For an offshore wind turbine it is proposed that the definition of wind turbine classes in terms of wind speed and turbulence parameters remains appropriate as the basis of design of the rotor – nacelle assembly. Furthermore, based on studies of the measurements of wind speed and turbulence from offshore sites, there does not appear to be sufficient justification for revision of the parametric values which characterise these classes for offshore wind turbines.

Wind turbine class	I	II	III	S
$V_{ref}$ (m/s)	50	42,5	37.5	Values specified by the designer
A $I_{ref}$ (-)	0,16			
B $I_{ref}$ (-)	0,14			
C $I_{ref}$ (-)	0,12			

**Table 1 – Wind turbine classes from IEC 61400-1**

In this table, the parameter values apply at hub height, and A designates the category for higher turbulence characteristics, B designates the category for medium turbulence characteristics, C designates the category for lower turbulence characteristics, and  $I_{ref}$  is the expected value of the turbulence intensity at 15 m/s.

#### *Wind conditions*

In general it is proposed that the wind conditions to be assumed for the design of the rotor – nacelle assembly of an offshore wind turbine will be the same as those for an onshore turbine as defined in IEC 61400-1 with a small number of exceptions. The exceptions are the reduction of the mean upflow angle to zero, a reduction of the wind shear power law exponent, and a possible reduction of the gust ratio associated with the 50 year return storm.

As stated above, the design of the support structure of an offshore wind turbine must be based on wind conditions which are representative of the specific site at which the offshore wind turbine will be installed.

#### *Marine conditions - waves*

Waves are irregular in shape, vary in height, length and speed of propagation, and may approach an offshore wind turbine from one or more directions simultaneously. The features of a real sea are best reflected by describing a sea state by means of a stochastic wave model. A design sea state is described by a wave spectrum,  $S_{\eta}$ , together with the significant wave height,  $H_s$ , a peak spectral period,  $T_p$ , and a mean wave direction,  $\theta_{wm}$ . Guidance regarding appropriate wave spectral models is given in an Annex to the standard. In some applications, periodic or regular waves can be used as an abstraction of a real sea for design purposes. A deterministic design wave is specified by its height, period and direction.

As is the case with the definition of wind conditions, the marine conditions are divided into normal conditions which occur frequently during normal operation of the turbine, and extreme marine conditions with a 1 year or 50 year recurrence period. The draft standard defines wave models in terms of both stochastic sea state representations and regular design waves. These are specified for normal and extreme conditions: normal sea state (NSS); normal wave height (NWH); extreme sea state (ESS); extreme wave height (EWH). In addition, the standard defines a severe sea state (SSS) and severe wave height (SWH) to represent “extreme” wave conditions which occur during wind conditions corresponding to power production of the wind turbine.

Finally, the standard uses the concept of a “reduced wave height (RWH)”. This is to be assumed in combination with the extreme gust wind speed averaged over 3s when both wind and wave conditions during a storm are represented as deterministic events rather than as stochastic realizations. The reduced wave height is used in this case since it is considered too conservative to combine the extreme gust wind speed with the extreme wave height.

The correlation of wind conditions and waves is crucially important for the design of an offshore wind turbine. In the context of “mean conditions”, this correlation must be considered in terms of the long term joint probability distribution of the mean wind speed, the significant wave height, and the peak spectral period. The joint probability distribution of these parameters is affected by local site conditions such as fetch, water depth, seabed topography etc. The distribution must therefore be determined from suitable long term measurements supported, where appropriate, by the use of numerical hindcasting techniques.

The distributions of wind and wave directions (multi-directional) may, in some cases, have an important influence on the loads acting on the support structure of an offshore wind turbine. The importance of this influence will depend on the nature of the wind and wave directionality and the extent to which the support structure is axi-symmetric. The designer may, in some cases, demonstrate by appropriate analysis that it is conservative and therefore acceptable to assume that the wind and waves are aligned (co-directional) and acting from a single, worst case direction (uni-directional).

In addition to the wave conditions described above, the draft standard requires that the influence of breaking waves be assessed during the design of an offshore wind turbine. Breaking waves are classified as spilling, plunging or surging; the first two types being relevant to sites suitable for offshore wind turbines. Although there is very great uncertainty regarding this topic, an Annex of the standard will provide guidance to determine the nature and dimensions of breaking waves based on site conditions as well as guidance to enable the calculation of the loading applied by the breaker to the offshore wind turbine support structure.

#### *Sea currents*

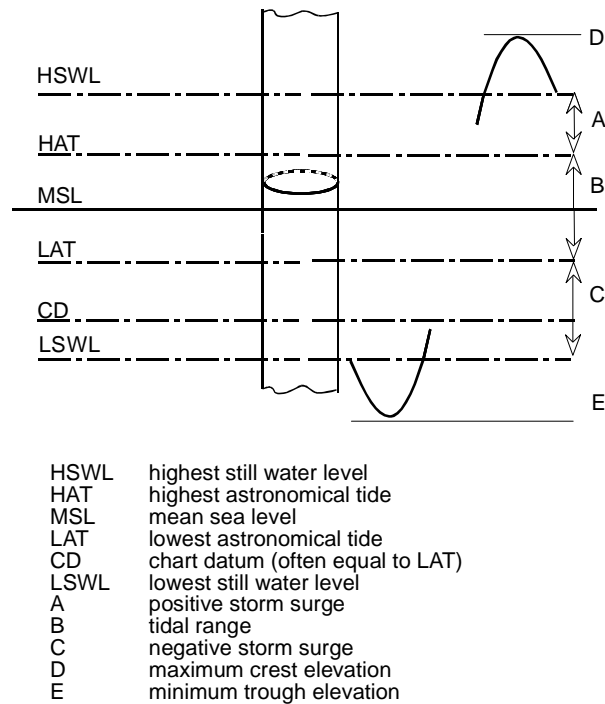
Although sea currents may, in principle, vary in space and time, they are generally considered as a horizontally uniform flow field of constant velocity, varying only as a function of depth. The draft standard requires that the following components of sea current velocity be taken into account:

- Sub surface currents generated by tides, storm surge and atmospheric pressure variations etc.
- Wind generated, near surface currents
- Breaking wave induced surf currents

The draft standard defines both normal and extreme current models (NCM and ECM) based on appropriate combinations of the above components of current velocity for the different design load cases.

#### *Water level*

For the calculation of the hydrodynamic loading of an offshore wind turbine, the variation in water level (if significant) at the site must be taken into account. The different relevant water levels are illustrated in Figure 2 below. The draft standard defines both normal and extreme water level ranges (NWLR and EWLR).



**Figure 2 – Water levels**

#### *Sea ice*

Static and dynamic sea ice loads acting on an offshore wind turbine are caused by current and wind induced motion of ice floes and their failure in contact with the support structure. The relevance of sea ice loads to the design of the support structure depends on the specific location and characteristics of the site at which the offshore wind turbine will be installed. The standard will require that the influence of sea ice shall be assessed during the design of the support structure. Guidance will be provided regarding such an assessment and the methods which might be used for calculation of ice loads.

#### *Marine growth*

Marine growth is broadly divided into “hard” (generally animal such as mussels and barnacles) and “soft” (seaweeds and kelps), where hard growth is generally thinner but rougher than soft growth. Marine organisms generally colonize a structure soon after installation but the growth tapers off after a few years.

Marine growth influences the mass, the geometry, and the surface texture of the support structure of an offshore wind turbine. Consequently, marine growth may influence hydrodynamic loads, dynamic response, accessibility and corrosion rate of the structure and must therefore be taken in to account during design.

#### *Scour and sand waves*

The support structure of an offshore wind turbine must be designed taking account of the extreme influence of scour and sand waves at the site. The analysis of the influence of scour and sand waves is particularly important in the context of the uncertainty and long term variation of the dynamic properties of the support structure.

### **2.2 – Load calculations**

In addition to the aerodynamic, operational and other loads experienced by an onshore wind turbine, an offshore wind turbine will experience hydrodynamic and sea ice loads. The

hydrodynamic loads acting on the support structure of an offshore wind turbine are able to affect the rotor-nacelle assembly only indirectly as a consequence of dynamic vibration of the support structure. This indirect influence of the hydrodynamic loads on the rotor-nacelle assembly is in general small, and possibly negligible depending on the dynamic characteristics of the support structure.

The draft standard requires that loads are calculated for a series of design load cases which, in common with the approach taken in IEC 61400-1, are based on combinations of:

- Normal design situations and appropriate normal or extreme external conditions;
- Fault design situations and appropriate external conditions;
- Transportation, installation and maintenance design situations and appropriate external conditions.

The external conditions to be considered for the design load cases will clearly involve wind and marine conditions. In addition design load cases associated with sea ice loading, boat impact and extended periods of non-production time have been defined. The latter, which might be caused due to non-connection and/or faults on the electrical network or in the wind turbine may have significant impact on both the fatigue and extreme loading of the wind turbine.

The standard will provide guidance with regard to the methods used for calculation of the loads acting on an offshore wind turbine taking account of:

- The dynamic response of the wind turbine to the combination of aerodynamic and hydrodynamic loads;
- Non-linear wave kinematics;
- Diffraction;
- Misalignment between mean wind and wave directions;
- The static and dynamic properties of the interaction of the foundation and seabed and the uncertainty and potential long term time variation of the dynamic properties due to scour, sand waves etc.

Many issues of relevance to the definition of calculation methods and design load cases have necessitated background sensitivity studies to be undertaken. These have been and continue to be performed by several members of WG3. In many cases the studies have been undertaken within the EU funded “RECOFF” project [6].

Partial safety factors for loads have been reviewed and decided upon. Consideration has been given to relevant onshore wind turbine design standards as well as standards appropriate to offshore structures. Decisions regarding safety factors clearly depend on what is considered to be the appropriate overall level of safety to be considered in the design of an offshore wind turbine. WG3 has decided that the target level of safety for the structural design of an offshore turbine should be the same as that for an onshore wind turbine in accordance with [4].

The draft standard requires that system and component design resistances of the support structure must be determined according to the ISO offshore structural design standards or other recognized offshore standards. For the tower, the design resistance may also be determined according to the requirements of IEC 61400-1. In general, if offshore standards other than the ISO standards are used it must be demonstrated that at least the same level of structural reliability with respect to ultimate strength and fatigue is obtained.

### **2.3 – Site assessment**

It is clear in the draft standard that both the design of the support structure of an offshore wind turbine and the demonstration of structural integrity of the rotor – nacelle assembly require an

assessment of the external conditions at the intended site. The procedures for such a site assessment therefore form a very important part of the standard.

The site assessment clause of the standard specifies requirements for the following:

- Establishment of the metocean database
- Assessment of waves
- Assessment of currents
- Assessment of water levels, tides and storm surges
- Assessment of sea ice
- Assessment of marine growth
- Assessment of scour and seabed movement
- Assessment of weather windows and weather downtime
- Assessment of seabed soil conditions

The assessment of wind and other conditions is covered in IEC 61400-1 and the requirements are therefore not duplicated in the draft offshore standard.

## **2.4 – Other issues**

The requirements stated in IEC 61400-1 with regard to the following have been reviewed within WG3 in order to identify revisions necessary for an offshore wind turbine:

- Control and protection system
- Mechanical systems
- Electrical system
- Assembly, installation and erection, commissioning, operation, maintenance and de-commissioning

In many cases it has been concluded that the requirements stated in IEC 61400-1 remain valid and are sufficient for offshore wind turbines and are not, therefore, repeated in the offshore design standard.

The standard also provides guidance with regard to the design requirements for the foundations of offshore wind turbines, with appropriate reference to the ISO offshore structural standards and indicating sources of other guidance.

## **2.5 – Annexes**

The draft standard includes a number of informative annexes containing guidance and background information relevant to many issues covered in the standard. Annexes are provided on the following topics:

- Design basis and key design parameters for offshore wind turbines
- Wave spectrum formulations
- Shallow water hydrodynamics and breaking waves
- Guidance on calculation of hydrodynamic loads
- Recommendations for design of offshore wind turbine support structures with respect to ice loads
- Offshore wind turbine foundation design
- Characteristic offshore wind turbine loads for ultimate strength analysis
- Statistical Extrapolation of Operational Environmental Conditions for Ultimate Strength Analysis
- Corrosion protection
- Bibliography



### **3 – Timetable**

Development of the 61400-3 began in 2000 and has taken longer than anticipated. There have been three main reasons for this:

1. Several technical issues faced by the working group have proved to be significantly more challenging than originally anticipated. In order to resolve these issues it has been necessary to await the outcome of a substantial body of background investigations and research studies.
2. The challenge of marrying wind turbine design requirements as specified in IEC 61400-1 with offshore structural design practice as codified in ISO 19900/1/2/3/4 has required very careful, time consuming consideration and discussion.
3. Work regarding some aspects of the offshore standard has awaited the outcome of the deliberations leading to edition 3 of IEC 61400-1.

The current status is that the major technical challenges faced by WG3 have been overcome, leaving the editorial finalisation of the text of the draft standard. The committee draft should be circulated to national committees for comment by the end of 2005.

### **4- Conclusions**

As the pace of development of offshore wind farms has quickened in Europe, and the interest in offshore wind energy has grown elsewhere in the world, the need for an international standard for offshore wind turbines is recognised as increasingly important. IEC TC88 WG3 was set up in 2000 and has brought together international expert knowledge from the wind power and offshore engineering industries to develop such a standard, IEC 61400-3. The major technical challenges faced by WG3 have been overcome and the committee draft of the standard will be released during 2005.

IEC 61400-3 is required on an urgent basis because the lack of a reliable and commonly accepted international design guideline has the effect of reducing the level of confidence with which currently planned offshore wind projects can be financed and implemented.

### **Acknowledgement**

The author acknowledges and thanks the members of WG3 for their hard work and commitment to the development of the international design standard for offshore wind turbines, IEC 61400-3.

### **References**

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